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DUCTOR THERMOELECTRIC DEVICES

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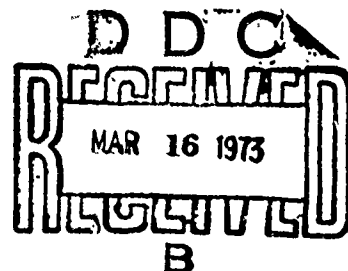LANGUAGE: COUNTRY: USSR

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PROBLEMS OF RELIABILITY OF SEMICONDUCTOR THERMO-ELECTRIC DEVICES

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Abstract. Various types of thermoelectric devices are
considered and their qualitative reliability indices
are presented. The area of applicability of the exponen-
tial law of the probability density distribution of rejec-
tions is described for computations on the devices mentioned.
On the basis of an analysis of the quantitative reliability
indices, and the design and technological features of the
devices, a series of recommendations are given with respect
to an increase of the reliability and quality of the devices
in question. Rejections are considered which took place
during tests and exploitation of the devices, and the most
common of them are considered with the object of demonstra-
ting the causes for their occurrence.

In conjunction with the development of semiconductor technology,
expansion of the range of its application in various fields of industry, as
well as the increasing complexity of the devices and apparatus themselves,
the need has arisen to determine and predict the quantitative indices of
reliability of the thermoelectric devices which have been developed and
manufactured [1 - 4]. The majority of concepts and criteria for reliability
are evaluated on the basis of a large volume of statistical material. How-

ever, at the present time the majority of thermoelectric devices that have been developed by Soviet industry lack equivalent analogs from the standpoint of reliability, while the lack of statistical data complicates the calculation or prediction of the quantitative indices of reliability and occasionally even makes it impossible to calculate and predict.

As the element of reliability of a thermoelectric device, the Special Design Office for Semiconductor Devices has adopted the thermopile module, consisting of several pairs of thermocouples, soldered in parallel. The thermopile module was selected due to the impossibility of testing its component parts under operating conditions (thermocouples, soldered joints and circuit boards with soldered connections) and for the purpose of taking into account the influence of the technology of using epoxy compound for potting. At the present time, there are many different forms of thermopile which differ in their design. This definitely complicates the collection of statistical data and determination of the failure rate.

The next problem involved in determining the quantitative indices of reliability of various thermoelectrical devices is the lack of methods of calculation. It has been shown that the probability density of failures of electronic components used in the construction of a given apparatus is distributed according to the exponential law.

However, at the present time we cannot state with complete reliability which law of distribution the probability density of failure of thermoelectric devices themselves obeys, since insufficient statistical material has been accumulated as of the present time.

To calculate the quantitative indices of reliability of thermoelectric batteries, the exponential law of distribution of probability of density of failures was adopted. On the basis of the available material and a qualitative analysis of the formula of general type for reliable operation of a thermopile

$$P(t) = \exp[-\lambda t]\left[\frac{1+\Phi\left(\frac{t-\tau}{\sigma}\right)}{1+\Phi\left(\frac{\tau}{\sigma}\right)}\right] \tag{1}$$

we can say that with $\tau > t$

$$\Phi\left(\frac{\tau-t}{\sigma}\right) \approx \Phi\left(\frac{\tau}{\sigma}\right)$$

and formula (1) will degenerate into the relationship $P(t) = \exp[-\lambda t]$. In these formulas, σ and τ are the mean-square deviation and average time of re-

liable operation (parameters of normal distribution, conditioned by failure as a result of aging); $P(t)$ is the probability of reliable operation of a thermopile during the time interval $t \epsilon (0 - t)$; $\phi(t)$ is the corresponding Laplace function.

With a reliable probability of 0.9, we can state that the neglect of aging of the thermocouples for a period of 7 to 8 years will introduce an error into the reliability index for reliable operation which will not exceed 1% of its value. We consider an error of this magnitude for rough calculations to be completely acceptable, since the technical resources of the devices which have been manufactured is sharply in excess of 36,000 ksec, while the service life is 3 to 5 years.

The systematization and analysis of the statistical data on the testing and operation of various types of thermoelectric devices allows the following conclusions to be drawn:

1. The average time of reliable operation of airconditioners with thermopiles of the "air-air" type and a refrigerating capacity of 860 to 5160 Watts is between 7200 and 1440 ksec (KR-1, KR-3, KR-2, KPR-5, KR-6).

2. The average time of reliable operation of thermostats with thermopiles of the "air-air" and "solid-air" type with thermostatted volumes from $0.5 \cdot 10^{-3}$ to 0.025 m^3 is between 2520 and 10,800 ksec (TLZ-25, TRK, TR-2, "Kvarts", TP-30).

3. The average time of reliable operation of refrigerators with 1-stage and 2-stage thermopiles of the "solid-solid", "solid-air" type is between 3600 ksec and 540,000 ksec (KhTD, KhFU-31, KhFK-R-72-K, B-1, TP-1).

In a more detailed analysis of the above types of thermoelectric devices (based on their schematic, design and technological forms), we can note the following relationships between the failure rates of the various units composing them:

1. In airconditioners with a high refrigerating capacity of the "air-air" type, the total failure rate for the control units and power supplies are either one order of magnitude or 1.5-4 times less than the number of failures in the thermoelectric section ($180-216 \cdot 10^{-5}$ 1/ksec; $216-648 \cdot 10^{-5}$ 1/ksec). From this it follows that it is necessary to increase the quantitative indices of reliability of thermoelectric batteries, since their numbers are very high. This problem may be solved by a series-parallel connection of the thermocouples in the thermopile.

It has been shown by calculation that the intensity of the failures in a similar thermopile module is 20 to 40 times less than indicated at the present time by the operation of the KR-2 airconditioner under actual conditions (more than 1800 ksec).

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2. In thermostats, the total number of failures of the control sections and power supplies are either one order of magnitude or more than 2 to 5 times greater than the number of failures of the thermoelectric device from $12.6-36 \cdot 10^{-5}$ to $72-216 \cdot 10^{-5}$ 1/ksec, except for the TLZ-25 thermostat, for which the ratio is 12:1. From this it follows that in order to increase the reliability of thermostatted conditions it is necessary to improve first of all the quantitative indices of the automatic devices, working out circuits using backup facilities for the weakest parts, mainly the output devices (the phase-sensitive output DC amplifiers, high-power switches, etc.) and the power supplies.

3. In the case of the refrigerators mentioned above, these rates of failure are in the ratio of 1:1 and in terms of their absolute magnitude are one order or less (from $22-44 \cdot 10^{-5}$ to $3.6-29 \cdot 10^{-5}$ 1/ksec), with the exception of the two-stage thermopile, in which the rate of failure is much higher ($100-270 \cdot 10^{-5}$ 1/ksec).

The authors tested a great many thermopiles of different types. They tested their working ability under the influence of various climatic conditions (temperature ranging from 223 to $330°K$, humidity from 65 to 100%, pressure from 4000 n/m^2 to 101, 325 n/m^2, etc.) and electrical influences. It was found that the majority of types of thermopiles suffered from the following types of failure:

1. Failure of the soldered junctions due to breakdown of the insulating layer of epoxy compound, leading to leakage of the working current to the housing, so that there was a decrease in the technical parameters of the thermopile. This took place either as the result of insufficient purity of the quartz filler or due to penetration of moisture, or as a result of oxidation of the circuit boards.

2. Failure of the thermopiles without soldered joints, due to changes in the resistance of the insulation. This took place for two reasons:

(a) During operation in a polluted atmosphere, there was a superficial deposition of salts, which led to local short-circuiting of the radiator and housing;

(b) In working in humid air, there was swelling of the epoxy compound resulting in short-circuiting to the housing.

3. Failure of the semiconductor thermocouple. This took place either due to poor soldering, which caused a break in the electrical circuit, or a mechanical disruption caused by temperature effects at various temperature coefficients of expansion for elements that were connected together.

To reduce the number of the above types of failures and thereby increase the reliability of the thermopiles, the following design and technological measures were taken:

(a) The requirements for purity and size of the quartz grains were increased for the manufacture of adhesive soldered joints, which excluded the possibility of penetration of metallic impurities;

(b) Improved soldered joints were made with beryllium oxide and attention was given to the problem of using thermopiles with screws to attach them to the electrically insulated surface;

(c) Technology was worked out for coating the thermopiles with electrically insulated paints of the Sbls and E4100 type to protect them against moisture..

The figures for the rate of failure of various types of thermopiles differ considerably, inasmuch as thermopiles differ in type, design, purpose, etc. However, a careful examination and study of all of these data shows the following characteristic: thermocouples that are intended for the same purpose and have the same design and technological features (thermoelements, connections, soldered joints, and heat emitters) show different degrees of reliability. The value for the coefficient of thermoconductivity for equivalent thermocouples varies very little - within the limits of accuracy of determination of these values. This fact makes it possible to determine for purposes of rough analysis the rate of failure of the planned batteries with a sufficiently accurate result.

In conclusion, we should like to emphasize once again the high degree of reliability of the planned thermoelectric devices, the simplicity of their maintenance and the possibility of increasing the quantitative indices of reliability following the solution of a number of technical and technological problems.

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